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A Demonstration of In Situ Energy Harvesting for Low-Power Instrumentation in the Marine Environment

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To demonstrate the generation of sustained electrical power from redox processes occurring on either side of the water-sediment interface in marine environments. To show a new form of power generation suited as a power source for long-term deployments of autonomous marine instrumentation requiring less than 1 Watt.

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Final Report

GRANT #: N00014-00-1-0290

PRINCIPAL INVESTIGATOR: Clare E. Reimers

INSTITUTION: Oregon State University

GRANT TITLE: A Demonstration of *In Situ* Energy Harvesting for Low-Power Instrumentation in the Marine Environment

AWARD PERIOD: 15 February 2000 - 31 March 2002

OBJECTIVE: To demonstrate the generation of sustained electrical power from redox processes occurring on either side of the water-sediment interface in marine environments. To show a new form of power generation suited as a power source for long-term deployments of autonomous marine instrumentation requiring less than 1 Watt.

APPROACH: The experimental approach was to:

- Construct small-scale, open-frame, fuel cells from circular 0.18 m^2 graphite plate electrodes.
- Package a programmable load/multimeter for logging cell potential and current under water.
- Deploy an active and inactive (control) cell at a site suited for land-based monitoring (Yaquina Bay, OR). Have divers bury anodes and connect the electrode wires of the active cell to the load.
- Monitor development of cell potential and its relation to environmental parameters (flow, T, S, O_2, pH, sediment chemistry).
- Determine voltage/current characteristics of the cell in a series of "polarization" experiments and in relation to environmental variables.
- Test sustainability of power by conducting continuous discharges at fixed currents or voltages for periods of 1 week to many months in duration.
- Recover cells and surrounding sediments to surmise anode reactions from chemical and biological changes at the buried electrode surface and in surrounding sediments.

ACCOMPLISHMENTS: Seafloor fuel cells showed sustained power densities of ~0.03 W/m^2 (footprint area of graphite plates) in Yaquina Bay, Oregon, from January 2001 to

January 2002. Small to moderate sinusoidal power anomalies observed on tidal and longer timescales could be attributed to environmental variables associated with estuaries. Sediment samples from above and next to the anodes of active and control cells revealed that power is generated, at least in part, from oxidation of dissolved and solid phase sulfides. Consistent with this finding, 60% of the microorganisms identified in scrapings of a biofilm from the active anode were from the *Desulfobulbus/Desulfocapsa* group of bacteria compared to a random mix of microorganisms attached to the control (Daniel Bond, U. Mass., personal communication). *Desulfobulbus/Desulfocapsa* are known for their ability to reduce elemental sulfur and other sulfur species of intermediate oxidation state to sulfide, using acetate and other simple organics as electron donors. Thus, microbial production of anode reactants is indicated.

<u>CONCLUSIONS</u>: The concept of harvesting power with a fuel-cell device at the sediment-seawater interface has been proven in the natural environment. Ongoing investigations are needed to focus on electrode optimization (to maximize the power density per area of seafloor), deployment (to install cells easily at coastal sites with water depths <1000 meters), power conversion (e.g., a step-up circuit for trickle charging a long-life rechargeable battery) and application (full-scale demonstration, powering ocean sensors).

<u>SIGNIFICANCE</u>: This research has demonstrated that low levels of sustainable power can be harvested from natural microbial and chemical redox processes at marine sediment-seawater interfaces. The natural separation of dissolved oxygen in seawater (cathodic reactant) and anoxic organic-rich sediment (source of anodic reactants) eliminates the need for a 2-compartment cell, semi-permeable membrane or other complicated materials for power generation. Our studies have also revealed new information as to how microbial populations and chemical distributions are coupled in the environment. Optimized "seafloor bio-fuel cells" appear practical for supplying long-term power to autonomous instrumentation such as hydrophones and chemical sensors in remote marine environments.

<u>PATENT INFORMATION</u>: A patent application related to using two electrode devices to harvest power from seafloor potential gradients has been filed.

AWARD INFORMATION: Awarded tenure at Oregon State University.

PUBLICATIONS AND ABSTRACTS:

1. Reimers, C.E., Tender, L.M., Fertig, S., and Wang, W. (2001) Harvesting energy from the marine sediment-water interface. Environ. Sci. Technol. 35, 192-195.

2. " Sea Batteries Keep Going and Going" (2001), Discover Magazine, 22(5), 14.

3. Tender, L.M., Reimers, C.E., Stecher, H.A. III, Holmes, D. E., Bond, D.R., Lowy, D.A., Pilobello, K., Fertig, S., Lovley, D.R. (2002) Buried treasure. Harnessing microbial power generation on the seafloor. Nature Biotechnology, in press.